INDUSTRIAS THERMOTAR LTDA. - DEMONSTRATIVE PROJECT FOR HCFC-22 PHASE OUT IN THE MANUFACTURING OF COMMERCIAL AIR CONDITIONING EQUIPMENT

UNDP REPORT

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Executive Summary

This demonstrative project was developed as response to the decision 75/40 by the Multilateral Fund Executive Committee in November 2015, and its aim was to demonstrate the safe use of HC-290 (propane) as an alternative refrigerant in the production of commercial air-conditioning (AC) equipment[1] at Industrias Thermotar ltda.

The HCFC-22 consumption in Colombia for the manufacture of commercial air-conditioning and refrigeration equipment is equivalent to 3% of the country's total HCFC-22consumption . This corresponds to the refrigerant charge of about 5,600 units manufactured per year. Currently, the the commercial air-conditioning models developed and manufactured are ducted split vertical condensing units and ducted package-type systems.

The project was carried out at Industrias Thermotar Ltda, a company that is responsible for great part of the country production of ducted split condensing units and package-type equipment with HCFC-22 . Thermotar average production is 4,100 units per year, about 17 to 20 units per day. This company consumes 60% of the total HCFC-22 consumption in the commercial air-conditioning sector. The company also manufactures the heat exchangers and the structure (metal-mechanics), and performs the electrical and other components installation, as well the refrigerant charging or precharging to the DACS.

In total, the company has eliminated 0.73 ODP tons (13.27 tons of HCFCs) through this project, which is essential for Colombia to comply with the HCFC phase out strategy for 2020. According to Decision XIX/6 this project applies proven non-ODS, negligible GWP technology. According to Thermotar environmental policy the company decided to switch from HCFC-22 to HC-290, considering the very low GWP[2] of HC-290, and LFL[3] equals to 2.1 % volume.

The country faced two main barriers to manufacture commercial AC equipment with hydrocarbon (HC-290) as an alternative refrigerant: The lack of knowledge and information of the sector on the technical aspects to be taken into account in the design engineering and manufacture of HC-290 AC equipment, and the technical weakeness of the personnel that provides the installation and maintenance services for these types of equipment devices. Therefore, the project included the participation of an international expert and the expertise of international supplier companies that work in the manufacturing of refrigeration and air-conditioning equipment with hydrocarbons.

In order to face the barriers mentioned above, the outcomes of the project were mainly based on demonstrating the safe use of HC-290 in the manufacture of commercial air-conditioning equipment between the ranges from 1 to 5 TR[4] (3.5 kW to 17.5 kW), and ensuring the safe and proper management of risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector,.

[1] DACS: Packaged and centralised ducted air-conditioning systems (Ducted split condensing units and ducted package-type units)
[2] Global Warming Potential, GWP, of HC-290 = 5
[3] Lower Flammable Limit. HC-290 = 0.039 kg/m3
[4] TR = Tons of Refrigeration

The demonstrative project consisted of five phases:

- Engineering design of AC equipment, which required a safety assessment of air-conditioning units considering the use of HC-290 (development of the explosion-protection features and quantitative risk assessment of new designs),
- Production line change installing new equipment in the manufacturing process (acquisition and installation of a leak-proof system, leak testing equipment, a storage station and feeding line for HC charging, a charging station for HC and a leak testing system for HC-charged equipment),
- Safety assessment of the production line (risk assessment and approvals from a third party),
- Training for the service area (training and qualification of staff in safe hydrocarbon refrigerant handling and management
- Organization of dissemination workshops.

Each of the above phases comprised the development of the following activities: Experiment or methodology design, recording of results, analysis of results (including lessons learned) and conclusions.

The following conclusions can be pointed out:

Through the demonstrative project condensing units and ducted package-type systems that work with HC-290 refrigerant were designed,. Different leakage and ignition tests were performed mainly on large-size prototypes (5 Tons of Refrigeration or 17.5 kW, prototype with a greater charge of HC-290 refrigerant). Among the technical and safety features of the new models, the following are highlighted:

- Reduction of the heat exchanger tube diameter (condenser): Two models of DACS were defined for both types of equipment; they differ in the material and diameter used in the manufacture of the condensing unit heat exchanger. (Aluminium microchannel heat exchangers and 8 mm copper tube heat exchangers). It should be noted that the designs and tests performed were applied to the largest model (5 TR), because these designs are replicable to the rest of HC-290 based DACS models.

- Reduction of HC-290 refrigerant charge: the estimated charge was 1,000 grams for ducted split condensing unit (5 TR) with five (5) meter pipe. The charge for the package-type condenser unit was 950 grams. The reduction in some cases was greater than 50% compared against the same HCFC-22 model.

- Modification of the metal structure (cabinet) of condensing units: The metal structure for both types of equipment were modified, similarly, the electrical boxes were individualized or insulated.

- Modification of the handling unit metal structure: The metal structure of the handling unit that is part of the split condensing unit was modified to insulate the electrical box and the entire frame, mainly the location of the air-intake area. This safety measure prevents high concentration levels of HC-290 inside an enclosure whenever an unexpected leak occurs.

- Pump Down cycle installation: The split condensing unit and the package-type unit have a "Pump Down" cycle, which collects the largest amount of refrigerant on the outside of the AC equipment specifically in the condensing unit. This occurs once pressure variations are detected through two pressure switches located in the air-conditioning system.

- Ultrasonnic sensor: The handling unit or equipment that is part of the split condensing unit has an ultrasonnic sensor for leak detection. This is an additional safety feature that prevents high levels of HC-290 concentration inside an enclosure, when an unexpected leak occurs.

- Power consumption: The Company carried out comparative tests related to energy consumption. A comparision between R-410A and HC-290 AC equipment (5 TR) was developed. The input power of the R-410A equipment compressor was 4,350 W and the input power for the new design with HC-290 was 3,780 W.

An adecuate conversion of the manufacturing line was made for HC-290 based DACS. The former HCFC-22 manufacturing line had the following stages: manufacture of the metal structure and heat exchangers, assembly of components and welding, vacuum, HCFC-22 charging, final leak test, quality control and packaging. A new manufacture line was installed to produce the HC-290 AC, and it is used for both types of air-conditioning (DACS). The new line has a manufacturing stage of heat exchangers and cabinets (these stages that did not change), assembling process, and an isolated main chamber with the necessary security measures for its operation. The tightness, pre-vacuum, vacuum, charge and leak tests are carried out in the chamber, as well as the reprocessing of non-conforming AC equipment. Similarly, as in the previous process with HCFC-22, the last stages are quality control and packaging of manufactured AC equipment. It must be noted that twenty (20) units are produced per day.

The security measures required by the new manufacture line and for the entire company were defined through the security assessment carried out by the insurance company contracted by Industrias Thermotar Ltda. In essence, the insurance company certified that Industrias Termothar LTDA implemented all the recommendations that arose during risk analysis study for the new HC-290 production line. Which means that new line has the protection measures that the foresaid line must have in order to guarantee its correct operation before, during and after each activity related to charging DACS with HC-290.

Training and coaching activities were carried out under supervision of the international consultant. This activities will continue at national level due to it has been included in programs related to training and education in the refrigeration and air-conditioning servicing sector. Additionally, as an integral part of this phase was generated technical document for updating of national standars (NTC 6828) based on ISO 5149, and a support plan was prepared focusing on the end user and the servicing sector.

And finallly the results and conclusions of the demonstrative project were presented in international and local events.

1. INTRODUCTION

The implementation of the demonstrative project for the use of HC-290 (propane), as an alternative refrigerant in the manufacture of air-conditioning equipment, was performed under the provisions of the UNDP PRODOC project 00097648, which considers the folloing topics:

- challenges for project implementation,
- strategy for project development,
- cooperation with other institutions,
- project management,
- results framework,
- monitoring and evaluation,
- multi-year work plan,
- management and governance arrangements
- and legal context and risk management issues.

The demonstrative project was carried out at Industrias Thermotar Ltda., a company that manufactures and consumes the largest amount of air-conditioning equipment and HCFC-22 refrigerant in the air conditioning sector in the country. According to the market data and company's production, the project focused mainly on the engineering design of ducted split vertical condensing units and ducted package-type units in the range from 1 to 5 TR (3.5 kW to 17.5 kW); two models were defined for each of these devices. These models differed in the material and tube diameter used in the manufacture of the heat exchanger of the condensing unit. (One aluminium microchannel exchanger model and an 8-mm copper heat exchanger model). It should be noted that the study and tests carried out by the international expert on the prototype concerning leakage and ignition, were developed for the prototypes that contain the highest refrigerant load: the split condensing units and the 5 TR package-type refrigeration equipment. This means that the design solutions adopted for these models were considered repeatable for the rest of the models contemplated in the project.

The phases and actions carried out during the project, within the framework of Stage II of the HPMP, are related to the elimination of the main barriers associated with the use of hydrocarbon refrigerants in the manufacture of commercial AC equipment, including training and certification of maintenance technicians and the establishment of technical standards for the management of hydrocarbons as a refrigerant in Colombia. Thus, the following objectives were established:

- to demonstrate the safe use of HC-290 (propane) as a refrigerant that has negligible global warming potential in the manufacture of commercial air-conditioning equipment,
- and to ensure the safe handling and good management of the risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector.

The present report details the development of the project implementation, including the completion the following activities: Tests and design procedures, recording of results, analysis of results

(including lessons learned) and conclusions, as well as the integration of the products obtained in each phase, in order to meet the goal and objectives proposed in the demonstrative project.

The following are some the phases, activities and actions carried out during the project:

- Development of prototypes and safety assessment of AC units for HC-290 application. The activities developed in this phase make up to the preliminary and final engineering designs for the models of commercial air-conditioning equipment with HC-290, the manufacture of prototypes, leak and ignition tests, and equipment testing.
- Conversion and installation of equipment in the manufacturing line. The activities and actions developed in this phase are related to the civil works required in the companies' production plant, the acquisition and installation of equipment and/or components needed to handle HC-290 hydrocarbon properly in the manufacture line, and the training of operators in charge of the manufacture line.
- Risk assessment of the manufacture line at Industrias Thermotar Ltda. The activities developed in this phase were related to the risk assessment performed on the hydrocarbon air-conditioning manufacture line.
- Technical training for the service of air-conditioner maintenance and installation. The activities developed in this phase were the training and qualification of the male technicians in charge of the installation and maintenance of new equipment. The international expert supported this activity. Additionally, two aspects have been considered in this activity to strengthen this phase, namely, the development of a follow-up plan focused on the end users who purchase these types of hydrocarbon air-conditioning equipment, as well as generate inputs for updating the Colombian Technical Standard, NTC 6828 based on ISO-5149.
- Dissemination of results. The activities and actions developed in this phase were related to the dissemination workshops and academic events about the lessons learned in the demonstrative project; they have been carried out during the project closure.

The results obtained from the demonstrative project for the use of HC-290 as an alternative refrigerant in the manufacture of air-conditioning equipment were the total elimination of the consumption of HCFC-22 refrigerant used in the manufacture of commercial air-conditioning equipment, and the safe promotion of this replacement alternative in companies that use other refrigerant substances (such as R-410A) with high GWP and that are associated with higher energy consumption. These results are achievable provided that the safe and proper management of the risks associated with the introduction of flammable refrigerants in the commercial air-conditioning sector of the country is ensured.

2. PROJECT OBJECTIVES AND IMPLEMENTATION

According to the document submitted and approved in the 75th meeting of the Executive Committee of the Multilateral Fund held in Montreal in November 2015, the project objectives were:

1. To demonstrate the safe use of HC-290 as a low GWP refrigerant in the commercial production of air-conditioning with ranging from 3.5 kW to 17.5 kW (1 to 5 TR), thus contributing to the phase out of HCFC-22 use in the RAC manufacturing sector. The aim was to develop HC-based AC equipment with good performance with a minimum incremental operating cost.

2. To assure safe handling and good risk management for the introduction of flammable refrigerants in the commercial air-conditioning sector.

Industrias Thermotar Ltda. is the factory that manufactures the largest share of the total volume of HCFC-22-based condensing units for air-conditioning systems and packaged air-conditioning equipment. Their principal users are trade outlets and retails located in tropical areas. The company served as a local technical host to coordinate the activities included in the demonstrative project phases since the new designs of equipment were incorporated into the diffusion workshop made to present the general results.

The project started last week in October 2016. It was implemented as a joint effort of Industrias Thermotar Ltda, Daniel Colbourne (International Expert of UNDP), Moji Trading S.A.S. (Agramcow: supplier company), the National Ozone Unit (UTO) and UNDP, and the Emerson Company (Copeland) that provided the compressors to be used in the project. The following activities were carried out:

Phases/Activity	**Period**	**Date**		
		2016	**2017**	**2018**
Designs and prototypes: Controllers and electrical components. Design of the refrigerant circuit, construction and prototype testing.	November 01, 2016 to March 31, 2018			
Installation of equipment in the manufacturing process: Installation and implementation of new equipment for the manufacture line. (Selection of the stationary equipment supplier, training for the operation and maintenance of the production line.)	December 01, 2016 to April 30, 2018			
Safety audit: Safety audit on the new manufacture line (Industrias Thermotar Ltda).	January 01 to March 31, 2018			
Training for servicing in installation during guarantee, post-sales services. (Updated Release of Colombian Technical Standard NTC 6828 based on ISO-5149)	October 01, 2017 to June 30, 2018			
Dissemination activities. Workshop for dissemination.	September 01, 2017 to July 31, 2018			

The execution period for the phase related to training of the service sector and update of the Colombian Technical Standard, NTC 6828 based on ISO-5149, was the period defined during the project development (see above), but this activities will continue at national level due to it has been included in programs related to training and education in the refrigeration and air-conditioning servicing sector.

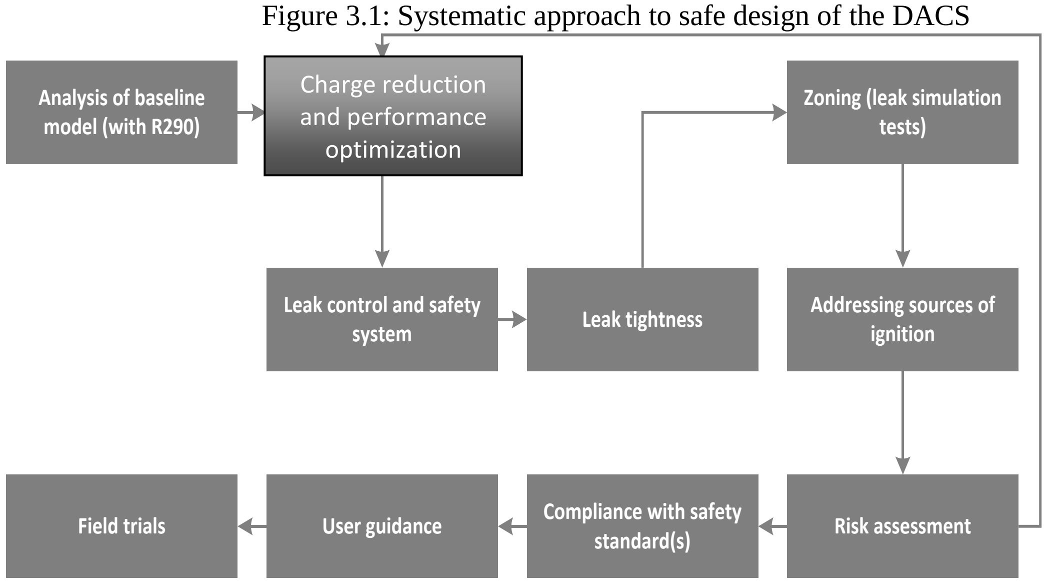
3. METHODOLOGY / EXPERIMENTAL

3.1 Experimental activities for safety assessment of HC-290 based DACS (see Annex A)

In order to place a product on the market – such as a DACS – it is necessary to ensure that it is safe and in compliance with applicable safety regulations. Whilst it is assumed that the baseline DACS designs (i.e., that currently use HCFC-22) already comply with the relevant requirements related to electrical, pressure and mechanical safety, an additional safety assessment is required for the use of flammable refrigerants . Therefore, it is necessary to re-assess whether any requirements of the DACS deviate from the HCFC-22 model due to the different properties and characteristics of the new refrigerant (HC-290) and its associated parts and components.

The work described in this report followed the sequence summarized in **Error! Reference source not found.** Essentially it was based on an iterative risk assessment/risk analysis approach, where each stage ultimately leads to a reassessment and refinement of the DACS design under development.

Figure 3.1: Systematic approach to safe design of the DACS



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

Several prototypes of both ducted split and rooftop units have been developed throughout this process, as summarized below:

Stage 1: HCFC -22 system charged with HC-290
Stage 2: Modifications to electrical components and enclosures/panels
Stage 3: Optimized condenser and inclusion of liquid line solenoid valve (LLSV[5]) and additional non-return valve (NRV[6])
Stage 4: Revised electrical components and enclosures/panels and AHU[7] return inlet construction
Stage 5: HC-290 compressor
Stage 6: Inclusion of leak detection system

The main task was to consider explosion protection in the design and construction of the unit. Additional measures were proposed for leak tightness in accordance with ISO 5149 and EN 1127-1 to ensure the system is technically tight. Further, tests were carried out to determine the releasable mass of refrigerant under various operating conditions. In addition to the general approach of safe design and construction, the unit is also assessed for compliance with NTC 6228, specifically for the requirements directly related to refrigerant flammability.

The DACS under consideration were packaged or centralized/split units mainly used for residential and commercial applications, where air-conditioning is supplied via ducting. The packaged unit is a single factory-sealed, pre-charged system. The centralized system comprises a separate indoor air handling unit (AHU) and an outdoor condensing unit.

The execution of this phase was carried out based on two activities: Development of the model designs for explosion protection and the quantitative risk assessments for these models.

3.1.1 Development of DACS designs for explosion protection

The design and construction of the DACS for explosion protection must be handled considering the risk minimization. Several basic principles, such as those as identified in EN 1127-1, focus on explosion prevention (as opposed to reduction of consequences). In principle, this requires:

- To reduce the amount of flammable.
- To avoid explosive atmospheres.
- To avoid all effective ignition sources.

The following aspects have been studied to fulfill of the above items:

a.) Leak tightness

Leak tightness is essential for risk reduction. A high level of leak tightness can be achieved through compliance with the following:

- Requirements for leak tightness testing in ISO 5149-2 clause 5.3.3 (and 5.3.2 for strength test).
- Ensuring the system is durably technically tight.
- Adopting additional design measures.

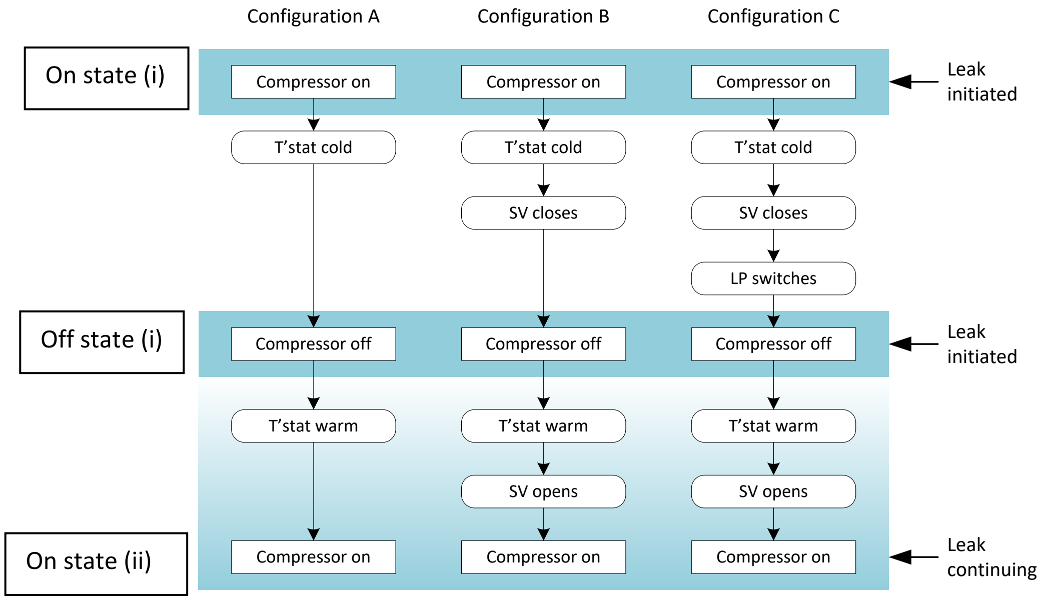
[5] SV: Solenoid valve – LLSV: Liquid line solenoid valve
[6] NRV: Non-return valve
[7] Air handling unit SEE COMMENT ABOVE ABOUT A LIST OF ABBREVIATURES

b.) Refrigerant charge minimisation: The redesign of the following parts was considered to minimise the refrigerant charge: Condenser, evaporator, compressor and overall system

c.) Releasable mass of refrigerant: It is important to establish how much refrigerant will be released from the system in the event of a leak and under different operating modes. Tests were conducted to quantify the refrigerant charge that could leak (released refrigerant mass):

Figure 3.2 presents the operating conditions and system configurations were considered to perform the refrigerant charge quantification tests.

Figure 3.2: Operating states for different system configurations



***Definitions**: T´stat cold: State of thermostat (cold). T´stat warm: State of thermostat (warm). LP switch: Low pressure switch. SV: Solenoid valve

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

It is important to point out that the system configurations used for the new DACS equipment were designed to locate the condenser unit (high side) on the outer part or outdoors.

The following procedures were developed with the methodology and arrangement used:

- To attache short, wide-bore hoses to chosen leak positions with the leak hole orifice at the end.
- To connect the outlet of the release orifice to a sealed collection bag.
- To operate the system for at least 30 minutes to achieve reasonably steady state conditions.
- To adjust the system operation to achieve the desired operating state and/or function
- To open valve to initiate the simulated leak.

The following devices and layouts were used:

- Ducted air-conditioners (ducted split and rooftop).
- 2.5 mm diameter (4.9 mm^2) leak orifice.
- Electronic pressure transducers.
- Electronic balance.
- Sealed collection bags.

d.) Characterization and avoidance of flammable concentrations: A release of refrigerant from either the internal or external parts of the DACS can form flammable mixtures. Ventilation, particularly mechanical ventilation, is known to provide risk reduction by assisting in the dispersion of a flammable refrigerant leak by increasing the entrainment rate and thus diluting the mixture below flammable limit rapidly.

The following methodology and arrangement were used to identify the location where flammable mixtures may form across various elements of the DACS and subsequently obtain the mass flow rate for certain leaks:

- To set up the room and equipment properly, including the placement of gas sensors at appropriate locations.
- To make sure all unintended sources of ventilation are removed.
- To initiate the release of refrigerant from the cylinder at the desired flow rate.
- To stop the flow once the released mass has been achieve.
- To wait as long as necessary until the end of test.

The following devices and layouts were used for the above:

- Ducted air conditioners (ducted split and rooftop) with fitted ducting, as required.
- Leak holes of various sizes (to suit specific leak conditions).
- HC-290 cylinder and hoses.
- Electronic balance.
- Electronic flow meter.
- Gas analysers with data logging.

e.) Removal of sources of ignition (SOI): The EN 1127-1 procedures were followed to remove these ignition sources. Here is a summary:

- To identify all possible points of leakage.
- To perform a hazardous area classification (zoning) exercise, as prescribed in IEC 60079-10-1.
- To check electrical (or non-electrical) components within zones with potential SOI.
- To remove those potential SOI from the zones, either by replacing them with non-SOI equivalent components or relocating existing components outside the hazardous area.

- Modifications to eliminate SOI.

This approach is included in the NTC 6228-2[8] draft and is intented for air-conditioning and refrigeration equipment. Accordingly, the leak simulation test method in the annex (NTC 6228-2) has been used for the zoning exercise.

f.) Limiting potential consequences and considering use and misuse limits: considers the activities that must be taken in account to limit the effects or consequences of an ignition event and those potentially hazardous situations associated to human interaction with an AC equipment or machine in accordance with EN ISO 12100, respectivily.

3.1.2 Quantitative risk assessment of AC new designs with HC-290

Quantitative Risk Assessment (QRA): The experimental model used in QRA was developed based on the operation (in-use) phase for the two DACS. Accordingly, the various equipment characteristics and environmental conditions that affect the likelihood of ignition of a flammable mixture are considered. This requires an analysis of the equipment and surroundings and integrating the findings into the basic methodology, namely:

- To select a range of leak hole sizes and determine the frequency of the occurrence of leak hole sizes.
- To estimate the average mass flow rate of release for each leak hole size.
- To identify each relevant operating mode (system on/off-cycle, fan on/off-mode; as applicable) and the external conditions (infiltration rates, presence of occupants, external SOI, etc.).
- To estimate the gas concentration within the unit compartment, flammable volume within unit compartment, gas concentration within room and flammable volume within room for each of the leak sizes, operating modes and sets of external conditions.
- To determine the probability of a flammable mixture within unit compartment and the probability of a flammable mixture within a room.
- To identify a set of potential sources of ignition (SOI) within the room and the unit compartment including their activation characteristics and location.
- To determine the probability of SOI and the corresponding frequency of ignition.
- To estimate the corresponding overpressure and thermal intensity for each circumstance that leads to an ignition event.
- To calculate overall risk values.

In order to carry out the calculations, it is first necessary to discretise the operation into segments according to the leak hole size, location of SOI, etc. A probability must be assigned to the occurrence of each event. Thus, the ignition frequency as well as the size of the consequent overpressure and thermal intensity can be estimated based on the estimated frequency of a release, size of flammable volumes and probability of active sources of ignition. These results then allow the calculation of risk values.

[8] NTC 6228 part 1 was updated and approved by the RAC sector and the part 2 exist as a draft which is being updated

After the quantification of all the elements discussed above, empirical data from field information, measurements and other validation techniques were used to improve the reliability of QRA results. The data, relevant parameters and DACS design and installation characteristics were based on discussions and measurements taken from previous studies (where relevant) and from technical literature.

The probability calculations used in normal operation are described in this section and include three main elements:

- Calculation of ignition frequency, consequence and risk for a given set of conditions.
- Calculation of the probability of occurrence for each set of conditions.
- Calculation of the overall ignition frequency and risk for the entire set of conditions.

These involve the estimation of contributing events, such as the occurrence of flammable concentrations and active sources of ignition and estimations of the probabilities of particular operating modes. In addition, the situation consists of two separate risks: a release into the condensing unit compartments and a release transferring into the room. Thus, the calculations are carried out according to:

- Ignition of a release within the applicable compartments within the DACS by an unintended potential SOI (i.e., a faulty or incorrectly fitted component).
- Ignition of a release within the room by other potential SOI normally present in the room.
- Ignition of a release surrounding the out-door parts of equipment caused by other potential SOI normally present outside.

A potential SOI is a device that may become a SOI under fault or failure conditions, but cannot ignite under normal operation, for example, a short circuiting in fan motor windings or a switch with a broken or incorrectly-fitted protective cover.

It is worth noting that event tree and fault tree analysis are used in the recording of results to determine the probability of each of these failure modes occurring and for each leak-hole size.

3.2 Methodology for the conversion and installation of equipment in the manufacturing line

The methodology used for the development of this phase was comparative, the expertise of different companies that execute the installation and assembly of these equipment lines worldwide was considered in the analysis.

The request for quotation form was drawn up for this purpose, which contained the technical specifications of the equipment and/or parts required for the new manufacture line, according to the country’s safety standards for the handling of flammable gases (refers to production lines used in the country's oil refineries). The systems required to convert the manufacture line are the following:

- A Helium leak test system with sniffer detector and helium recovery equipment
- Pre-vacuum system and vacuum pressure leak test.
- Evacuation equipment and flammable refrigerant charge (HC-290).
- Equipment for safe discharge and evacuation of flammable refrigerant (HC-290).
- HC-290 detector equipment for leakage testing in manufacturing and reprocessing areas.
- Additionally, the safety monitoring and control system for flammable gases (HC-290) was included, together with the ventilation system for flammable gases.

The companies that submitted their proposals in accordance with the request were: POLO SRL, VPC INGENIERIA S.A.S (Galileo); MOJI TRADING S.A.S. (Agramkow Fluid Systems A/S). The selection process favoured the Agramkow Fluid Systems A/S company, which defined a work plan including the following activities: Preparation of the equipment drawings for the manufacture line, determination of the civil works required in the delimited installation for the assembly of the acquired machines, restructuring of the supply system of oxyacetylene sources, dry air and electrical connections and the construction of the charging area and leakage test, by means of an aluminium profile cabin, which delimits the area for the handling processes of HC-290 flammable refrigerant gas.

3.3 Risk assessment of the manufacture line at Industrias Thermotar Ltda

Two reports were made in the development of this phase; a first report related to risk analysis for the implementation of HC-290 LPG[9] at Industrias Thermotar Ltda and a second report on the follow-up to the recommendations for the implementation of HC-290 LPG at Industrias Thermotar Ltda.

The experimental test was carried out based on the fulfilment of three objectives. First, determining the most significant risks that arise or can be identified, regardless of their characteristics; second, assessing those risks, that is, the probability of occurrence and level of impact in case they materialise; and the final objective is to determine how to handle those specific risks, that is, determine the path to be followed, through a loss control or risk reduction program.

A risk map of the process was prepared for the risk identification stage in the implementation of this new refrigerant. Also, the respective scales of probability of occurrence and level of impact applied to each risk —and therefore, to each one of the stages of the HC-290 charging process— were defined to assess those risks.

The evaluation took into account the expertise of the insurance company of Industrias Thermotar Ltda, who previously knew the manufacture line.

3.4 Training for servicing in installation during guarantee, post-sales services

[9] Pressurized Liquefied Gas

The training process included both theory and practice workshops, which were supported by the international expert that organized and formulated technical contents that focused on the safe handling of HC-290 refrigerant during the installation, maintenance and disassembly services of the new air-conditioning equipment.

Additionally, the guidelines and methodology established through the National Standardization Agency of Colombia INCONTEC (Colombian Institute of Technical Standards and Certification) were considered to generate inputs in order to update the NTC 6828. Likewise, in order to carry out this update, an interdisciplinary working group was formed among the different actors involved in safety and environmental requirements needed in refrigeration systems and heat pumps. It should be noted that the international expert consultant supported the update of the NTC.

Finally, while preparing the follow-up plan, Industrias Thermotar Ltda used its experience on preventive maintenance operations to develop a follow-up plan for the operation of the new air-conditioning equipment installed in the commercial sector (customers).

3.5 Workshops for dissemination of results

The dissemination workshops involved presenting or socializing the results obtained in each project phase to the interested public. Additionally, the dissemination and communication included the preparation of research papers or documents on the results obtained.

4. RESULTS

4.1 Prototypes and safety assessment of HC-290 based DACS

The DACS specifically addressed under this project are identified inTable 4.1, although it has mainly focused on the 17.5 kW units; if the safety issues associated with the largest units are met, applying HC-290 to the smaller units should be less of a challenge.

Table 4.1: Models to be addressed for HC-290 application

Capacity	Centralised ducted split	Packaged rooftop
7 kW (2TR)	CV024 + FCD024	EPAC-024
10.5 kW (3TR)	CV036 + FCD036	EPAC-036
17.5 kW (5TR)	CV060 + FCD060	EPAC-060

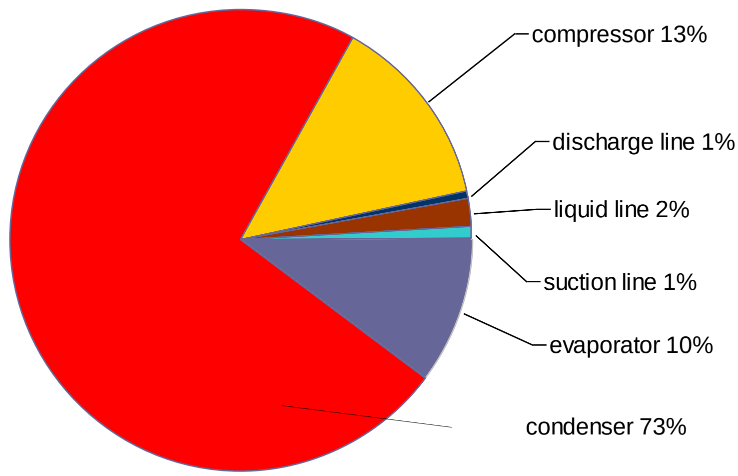
Source: Industrias Thermotar Ltda.

4.1.1 Development of the prototypes with design for explosion protection

a.) Leak tightness: Circuits and piping were examined and checked in the development of prototypes to minimize their vulnerability to leakage. Final design models were re-checked for compliance with leak-tightness requirements (ISO 5149-2 clause 5.3.3).

b.) Refrigerant charge minimisation: **Error! Reference source not found.** 4.1 shows the usual refrigerant charge distribution for an ACU[10]. This implies that most benefit for change reduction can be gained from addressing the condenser. Although the compressor can yield potential charge reduction, it depends on the efforts of the compressor manufacturer.

Figure 4.1: Typical refrigerant charge distribution in an air-conditioning system



Source: Prototype designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- Condenser: The most significant modification was to reduce the tube size from 9.5 mm diameter to 7.9 mm. In addition to the finned tube condenser, a parallel prototype has been developed with a micro-channel condenser which also provides charge reduction.
- Evaporate: The analysis and redesign of the evaporator coil have not been performed in this Project.
- Compressor: The compressors used within the new DACs are HC-290 compressors. These compressors have more appropriate electrical components. (compressors were provided by Copeland - Emerson.)
- Overall system: The refrigerant charge had been reduced from approximately 1,300 – 1,400 g HC-290 to about 1,000 g with the finned tube condenser in the ducted split and with the standard 3 m interconnecting piping. Table 4.2 provides the current and estimated charge sizes for the six models under consideration.

Table 4.2: Models with HCFC-22 and anticipated HC-290 charge sizes

Charasteristics	Rooftop			Ducted split		
Model number	EPAC-036-	EPAC-048-	EPAC-060-	CV036-	CV048-	CV060-
Nominal capacity	10.5 kW	14 kW	17.5 kW	10.5 kW	14 kW	17.5 kW
HCFC-22 charge	1300 g	1775 g	2210 g	1360 g	1815 g	2265 g
HC-290 charge	560 g	760 g	950 g	600 g	800 g	1000 g

Source: Industrias Thermotar Ltda.

[10] Air condenser unit

c.) Releasable mass of refrigerant: The final results were obtained with the prototypes including HC-290 compressors. These tests primarily focused on “pump-down” and “shut-down” conditions and should provide the actual releasable refrigerant amounts for the developed (“5TR”) models. Three measurements were carried out for both ducted split and rooftop models, for the pump-down and shut-down cases.

The following observations can be made based on the results compilation of Table 4.3:

- The use of pump-down cycle is more effective to retain refrigerant in the system in the event of a leak from the low side.
- Relying on a LLSV only but without pump-down when compressor terminates in 3 – 4 times as much charge being released (than with pump-down).
- Relying on the LP[11] switch to close the system and prevent more refrigerant from leaking is not particularly effective, since more than half the charge will be released.
- Leak from the high side will release almost the entire charge (outside).
- Wherever a LLSV is used to limit the amount of refrigerant that may be released, average leak rates tend to be lower, with mass fluxes ranging 15 – 25 g/min per mm^2.
- Leak rates from the low side are approximately double when there is no closed LLSV, which is due to the driving force of the refrigerant migrating from the high-pressure side of the system.
- Releases from the high-pressure side result in average leak rates two to five times higher than those from the low side, mainly due to the higher pressure and the greater amount of refrigerant held locally.
- Mass flow rates in the boiling stage when the compressor is off are generally one and a half to two times the average mass flow, an expected result due to higher pressure during that stage and occasional liquid droplets.
- When a leak occurs whilst the compressor is on, mass flow in the boiling stage is almost the same as the average mass flow since the low-pressure side is continually replenished with liquid most of the leak period.
- There is a negligible boiling stage for leaks from the low side following pump-down due to the prior removal of most of the refrigerant.

[11] Low Pressure

Table 4.3: Summary of leak amount tests conditions and results

Test No.	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av. leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
3	Duct split	low side	On --> off; LLSV closed	1009	395	934	93%	86	25	186	54
4	Duct split	high side	Off; remaining	1009	540			184	53	344	99
5	Duct split	low side	On --> off; LLSV closed	1050	434	957	91%	43	12	87	25
6	Duct split	high side	Off; remaining	1050	522			182	53	305	88
7	Duct split	low side	On --> off; LLSV closed + DNRV	1043	327	880	84%	82	24	156	45
8	Duct split	high side	Off; remaining	1043	554			190	55	321	93
9a	Duct split	low side	On; pump-down	1035	40	912	88%	31	9	n/a	n/a
9b	Duct split	low side	On; pump-down	1035	54			34	10	n/a	n/a
9c	Duct split	low side	On; pump-down	1035	51			33	9	n/a	n/a
10	Duct split	high side	Off; remaining	1035	767			231	67	371	107
11	Duct split	low side	Compr on; LPS --> off	1035	537	832	80%	44	13	47	14
12	Duct split	high side	Off; remaining	1035	295			141	41	328	95
13	Duct split	low side	Compr on; LPS --> off	1120	522	1076	96%	189	55	184	53
14	Duct split	high side	Off; remaining	1120	554			126	36	203	59
15a	Duct split	low side	Compr on; LPS --> off	1120	557	994	89%	134	39	130	38
15b	Duct split	low side	Off	1120	114			81	23	142	41
16	Duct split	high side	Off; remaining	1120	324			145	42	315	91
17a	Duct split	low side	On; pump-down	1400*	236	1366	98%	54	16	n/a	n/a
17b	Duct split	low side	On; pump-down	1400*	142			49	14	n/a	n/a

Test No.	Unit	Location	Mode	Charged (g)	Leaked mass (g)	Total leak mass (g)	Leaked fraction of charge (%)	Average leak rate (g/min)	Av. leak mass flux (g/m/mm^2)	Leak rate (boiling) (g/min)	Leak mass flux (boiling) (g/m/mm^2)
17c	Duct split	low side	On; pump-down	1400*	97			60	17	n/a	n/a
18	Duct split	high side	Off; remaining	1400*	892			212	61	304	88
19	Duct split	low side	On; pump-down	880	80	80	9%	63	13	n/a	n/a
20	Duct split	low side	On; pump-down	880	83	83	9%	66	13	n/a	n/a
21	Duct split	low side	On; pump-down	880	77	77	9%	61	12	n/a	n/a
22	Duct split	low side	On; shut-down	880	273	273	31%	115	23	237	48
23	Duct split	low side	On; shut-down	880	349	349	40%	125	25	218	45
24	Duct split	low side	On; shut-down	1010	352	352	35%	126	26	236	48
25	Duct split	low side	On; pump-down	1010	68	68	7%	51	10	n/a	n/a
26	Rooftop	low side	On; pump-down	1100	88	88	8%	69	14	n/a	n/a
27	Rooftop	low side	On; shut-down	1100	278	278	25%	83	17	122	25
28	Rooftop	low side	On; pump-down	1100	51	51	5%	40	8	n/a	n/a
29	Rooftop	low side	On; shut-down	1100	295	295	27%	80	16	145	30
30	Rooftop	low side	On; pump-down	1100	60	60	5%	31	6	n/a	n/a
31	Rooftop	high side	On; shut-down	1100	284	284	26%	83	17	157	32

* System overcharged; released quantities deemed to be higher than those obtained from a correctly charged system. Test No 1 and 2 were considered like proof

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

d.) Characterisation and avoidance of flammable concentrations: As mentioned above, the two main reasons for testing are: to determine the releasable charge under a given set of conditions and subsequently obtain a mass flow rate for leaks of a certain size.

- AHU enclosure: Concentrations within the ducted split AHU enclosure for the two leak positions are shown in Figure 4.2 and Figure 4.3. The results are similar in both cases; there is an initial rapid increase in local concentration and then a transition to a fairly steady value with further addition of refrigerant as the mixture migrates from the openings within the AHU envelope. Seconds after the leak stops, both sampling points fall towards zero. As expected, concentrations are higher at the base than at the top of the enclosure. Importantly, the concentration easily exceeds the LFL[12] with this leak size, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed the LFL.

Figure 4.2: Leak position 1, 220 g, 50 g/min

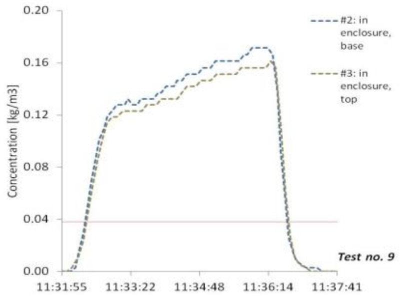
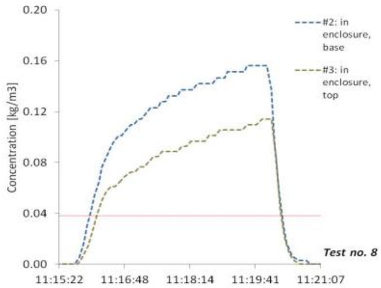


Figure 4.3: Leak position 2, 220 g, 50 g/min



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

With the blower on, the measured concentrations were negligible. Even with a release of 530 g at 135 g/min and the blower on "low" setting, the concentrations were below 0.005 g/m3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of 0.003 kg/m3 – about 7% of the LFL of HC-290.

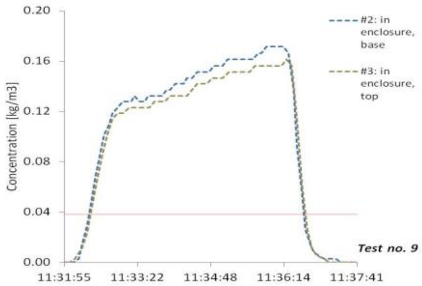
The behaviour is slightly different compared to the case of ducted split AHU enclosure in firstly, the initial jump in concentration is substantially higher with the rooftop AHU, likely due to a smaller internal volume. (The fact that a larger mass is used in the rooftop tests is not important since it does not affect the initial values.) Secondly, whereas concentration increased gradually over time with the ducted split AHU, those within the AHU reach equilibrium within a couple of minutes into the release. This is due to differences in the size of openings through which the mixture can flow out; whilst the rooftop AHU has a smaller internal volume, the gaps are larger (for example, comparing the internal volume) thus enabling a higher outflow rate.

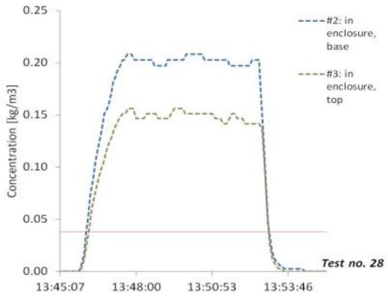
Concentrations within the rooftop AHU enclosure are shown in

Figure 4.4: Leak position 1, 380 g, 50 g/min

Figure 4.5: Leak position 2, 380 g, 50 g/min

[12] Lower flammable limit. HC-290 = 0.039 kg/m3





Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

4.4 and Figure 4.5 for the two leak positions. In both cases the results are similar, where there is an initial rapid increase in local concentration and these then transition to a fairly steady value with further addition of refrigerant as the mixture migrates from the openings within the AHU envelope. Within seconds of the leak stopping both sampling points fall towards zero. As would be expected, concentrations at the base are higher than at the top of the enclosure. Importantly, with this leak size, the concentration easily exceeds the LFL, demonstrating that the entire internal space is potentially flammable. Even with a fraction of the charge, the concentration would still exceed LFL.

Figure 4.4: Leak position 1, 380 g, 50 g/min

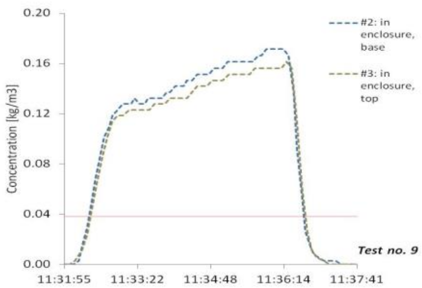
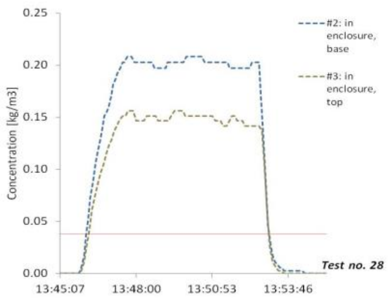


Figure 4.5: Leak position 2, 380 g, 50 g/min



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

As with the ducted split AHU, with the **blower on,** the measured concentrations were negligible. Using a release of 350 g at 230 g/min and the blower on “low” setting, the concentrations were below 0.005 g/m3 (on account that the sensors did not return a value). Dividing release mass flow rate by the blower volume flow infers an average concentration of just under 0.005 kg/m3 – about 12% of the LFL of HC-290.

– Condensing unit enclosure: Concentrations within the rooftop condensing unit enclosure are shown in Figure 4.6 and Figure4.7 for the two leak positions. As with the releases inside the rooftop AHU enclosure, there is an initial rapid increase in local concentration and these then transition to a relatively steady value as further refrigerant is released, although only at the lower sampling location. Despite the mass flow being 2.5 times greater than the AHU tests, this concentration equilibrium occurs due to the considerably larger free area in the housing, i.e., between condenser fins and the fan housing. The sampling locations towards the top of the enclosure are rather erratic and relatively low, due to rapid ingress of fresh air. Whilst at the base the concentrations exceed LFL, those at the top are comfortably lower than LFL.

Figure 4.6: Leak position [discharge pipe], 1000 g, 150 g/min

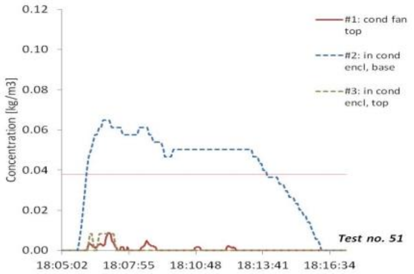
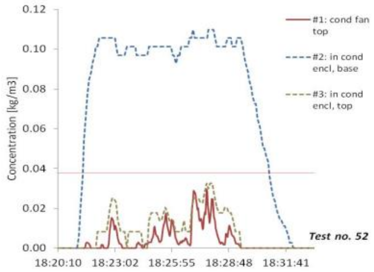


Figure 4.7: *Leak position [liquid line], 1000 g, 150 g/min*



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

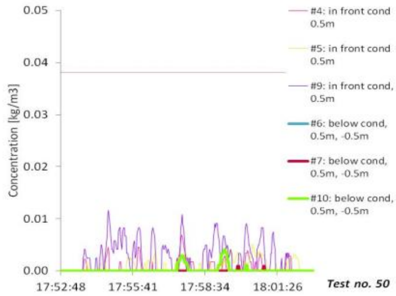
- Ducting: Provided that the velocity is high enough to cause turbulent flow within the ducting – which is the case in most applications (i.e., Reynolds number is several orders of magnitude higher than that at transition between laminar and turbulent flow) it is likely that any refrigerant travelling along the duct with forced airflow will become very well mixed. When the blower is off, high concentrations can be found at duct outlets, but this depends upon how much of the refrigerant can flow back through the return ducting or through the supply ducting. If duct outlets were elevated then any refrigerant flowing from the outlet will dilute to low concentrations within a fraction of a metre along its decent. Where duct openings are positioned at floor level, significant concentrations can be found and mitigations measures are recommended.

- Beyond condenser for DACS: Whilst releases from the condenser part of the rooftop unit, or the condensing unit of the ducted split unit are broadly of a lesser concern than leaks indoors, it is useful to understand how the refrigerant will distribute around the unit housing. In particular, this contributes to determine "separation distances" from the unit to other electrical equipment or fresh-air inlet ducts installed nearby.

  Measurements were made using the rooftop unit and condensing unit of the ducted split, positioned on an elevated board. This is intended to more accurately represent an outdoor installation, where a release is not confined by room walls. Measurements were carried out indoors, where airflow is limited; usually outside airspeed is substantially higher and therefore these results represent a very pessimistic case. Whilst only the rooftop unit was used for these tests, the results are deemed to represent the condensing unit since the construction of the condenser parts is almost identical.

Figure 4.8: Arrangement of the rooftop unit for surrounding concentration measurements

Figure 4.9: Concentrations surrounding the rooftop unit at 0.5 m and 0.5 m below plinth with 1000 g at 150 g/min from discharge pipe, with access panel open



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

e.) Removal of sources of ignition: Due to the relatively confined construction of the various DACS housings, a release from any point rapidly ensures any position within the housing would exceed 50% of the LFL. Therefore, it is necessary to position any potential SOI into an externally located panel.

Most electrical components (many of which could be a potential SOI) are located within inset electrical panels. Ordinarily this comprises (e.g., Figure 12): Mains relays, start capacitors, run capacitors, voltage transformers, timer/delay and terminal connections.

Of these, only the relay and timer/delay could be considered as a potential SOI (see below).

Figure 4.10: Typical contents of electrical panel

Figure 4.11: Example of evaporator fan motor

Figure 4.12: Example of fan blades

Source: Industrias Thermotar Ltda.

The evaporator fans are located within the AHU housing and are thus likely to come into sustained contact with refrigerant in the event of a leak. Therefore, significant attention should be paid to them in order to avoid ignition sources. Condenser fans are positioned at the top of the condensing unit and normally located in the open air. A leak of refrigerant is unlikely to accumulate around the condenser fan so limited attention may be paid to them.

Both condenser fan and evaporator fan motors are AC induction type and do not present a SOI under normal operation since they are brushless. They do use internal overload protectors.

All fan blades are aluminium, whilst the cowling is galvanised steel. Provided that the fan and cowling materials are not stainless-steel pairs or steel alloy and brass pairs, the possibility of sparking due to mechanical impact is negligible. The following must be complied with to ensure that the fan assembly has negligible risk of producing arcs and sparks:

– Rotational speed should be less than 40 m/s.

- Powder coating must not contain aluminium or iron oxides.
- All metal parts of the fan assembly and parts are earthed, which avoids the possibility of static build-up.
- Clearance distance between the fan blades and the casing shall be at least 1% of the diameter and no less than 2 mm.

The high and low-pressure switches are basic fixed-value encapsulated switches. They are likely to be suitable. However, several manufacturers are producing HC-290 approved components; these should be sought first before considering the use of HCFC-22 components. If HCFC-22 items are applied, then it is recommended they are checked for compliance against IEC 60079-15, e.g., for enclosed-break device.

With regard to compressor currently are used Copeland HC-290 scrolls. Whilst they comprise internal windings and thermal overloads; the only external electrical parts are terminals and wires and have nevertheless been certified against the applicable Standard. As such, they do not present as SOI under normal operation.

Figure 4.13: Example of pressure switch

Figure 4.14: Example of compressor (left) and electrical connection (right)

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

A normally-closed solenoid valve was installed within the liquid line to limit the releasable charge. Since solenoid valves do not arc or spark under normal operation, they are not considered SOI. However, it is advisable to select approved HC-290 SVs.

The electrical panel contains one 2/3-pole mains relay. Whilst it is intended to position the electrical panel external to the housing, it is desirable to check the construction of the used relays against the requirements for enclosed break device under IEC 60079-15 in order to provide additional confidence.

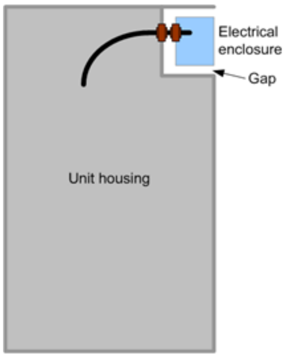
Figure 4.15: Example of mains relay employed

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

In response to the initial zoning exercise, several components needed to be relocated out of the zone 2 area (condenser unit). This was achieved by redesigning a panel located in an air-separated section; in this regard, even if the inset section is not sufficiently tight to prevent egress of leaked refrigerant, it should be unable to penetrate the second enclosure. A prototype is included in

Figure 4.16 along with a schematic.

Figure 4.16: Current (left) and proposed (right) electrical panel



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

By following the leak simulation test (zoning exercise) detailed in NTC 6228-2, it was demonstrated that the revised construction avoided contact with a concentration exceeding 50% of the LFL.

Separating the electrical panel ensures that if a technician inadvertently fits an unsuitable component after the units has been installed, there remains no residual risk that it could act as a SOI to a refrigerant leak.

f.) Limiting potential consequences and considering use and misuse limits: The preferred approach to avoiding or minimising the severity of consequences is prevention of ignition by removal of SOI and curtailing the formation of flammable mixtures. However, as long as flammable substances are being employed, their avoidance cannot be absolutely guaranteed. Therefore, additional consideration should be given to limiting the effects of such consequences. Typical approaches include:

- Physical barriers among potentially flammable mixtures, occupants and combustible materials.
- Non-combustible construction materials to avoid secondary combustion.
- Sufficient free openings or frangible sections for enclosures to allow overpressure relief.

These considerations are included within the operating manual of the new DACS designs, pursuant to NTC 6828.

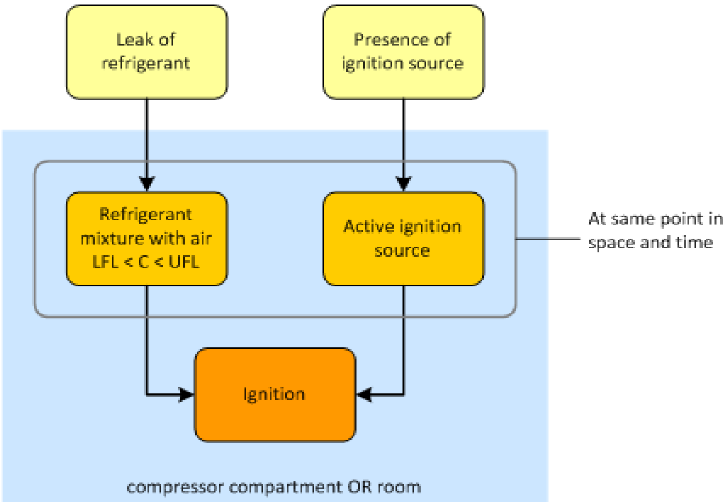
4.1.2 Quantitative risk assessment of new DACS designs

It is necessary describe the generic operating and environmental conditions that could affect the likelihood of ignition in order to quantify the normal operation risk. Consequently, it is also necessary to characterise the three co-incident events that are necessary to cause ignition:

- A leak of refrigerant that enters a given control volume (enclosure, room, etc.).
- Formation of a flammable mixture.
- At the same time, presence of an active SOI within the condensing unit compartment or room.

This general sequence of events is shown in Figure 4.17

Figure 4.17: General sequence of events for normal operation



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

The variables will be described in more detail to identify effectively the condition that could lead to ignition of a release within each stage. Various leak sizes are considered (ranging from "pin hole" to "catastrophic"), the compressor operating mode (in these smaller systems with no mechanical joints, the leak characteristics are considered to be largely unaffected by compressor operation. Therefore, this parameter is neglected), an evaporator blower or condenser fan may or may not be operating on the DACS, creating an internal airflow within enclosure, ducting and the local area.

Ambient air movement: Various forms of airflow can affect the dispersion of the refrigerant and therefore the size and duration of a flammable volume. Indoors, this can arise from infiltration, thermal convection currents and movement of personnel; outside, it can be caused by the wind.

The frequency of fatalities can indicate the severity of the secondary consequence. However, this study found that the consequence of ignition is very unlikely to cause overpressure or a thermal dose that could result in a fatality; therefore, the number of occupants is not applied, except in terms of their distribution, implying an average distance from the ignition event.

The size of the room can affect the build-up of gas concentrations and thus the occurrence of a flammable mixture within the room. Only one room size is opted for, a particularly small space where these types of appliances are normally located.

The Results for the relevant risk measures associated with the various control volumes are:

- Ducted split:

  The main observations concerning ignition frequency are:

  - Both AHU and condensing unit have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
  - Ignition within the supply duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
  - Ignition within the room floor region is very small, less than one ignition event per 1,000 million units per year and as such also has no significance.
  - Ignition frequency within the space through which the interconnecting piping runs is fairly small (about two ignition events per 10 million units per year).
  - The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

- Rooftop

  The main observations concerning ignition frequency are:

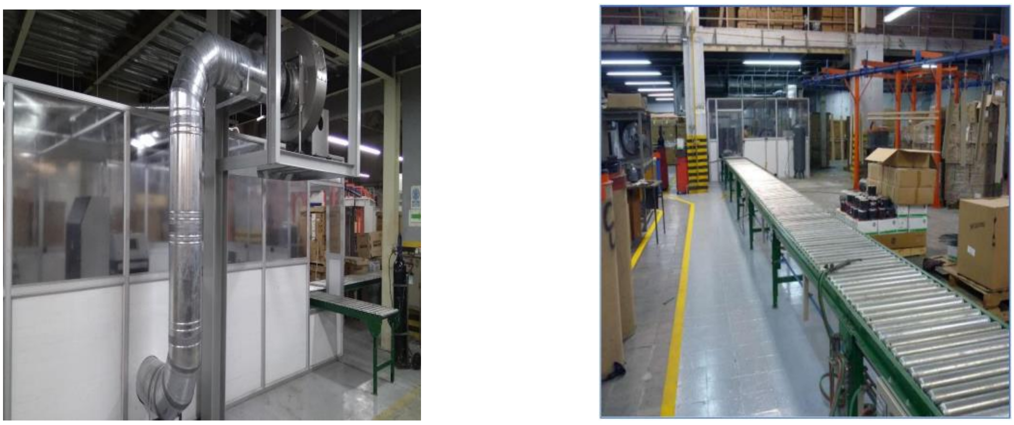
  - Both AHU and condensing unit section have extremely low ignition frequencies, corresponding to less than one ignition event per million-million units per year; such a frequency is so low it may be considered negligible.
  - Ignition within both with the supply and return duct is also negligible (on account that the only ignition source is another ignition event within an adjacent space).
  - Ignition within the room floor region is very small indeed, about one ignition event per million-million units per year and as such is negligible.
  - The control volume which experiences the highest ignition frequency is the area surrounding the condensing unit, with about three ignition events per millions units per year.

4.2 Conversion and installation of equipment in the manufacturing line

During project execution, the modifications and civil works required for the new infrastructure were made, and the new manufacture line of HC-290 air-conditioning equipment was installed. As a relevant

fact, the new production line has an insulated chamber, which is five (5) meters apart from any other type of equipment that is part of the manufacturing plant. In addition to containing all the equipment that is part of the manufacturing process, this insulated chamber has a hopper located in the lower part of the conveyor belt, which has a hydrocarbon extraction and permanent air-renewal system (explosion-proof extractor). This system is energized at its maximum power by more than one hydrocarbon sensor (HC-290) located inside the hopper and insulated chamber. Additionally, the new line is powered by four (4) non-rechargeable 5.5 kg HC-290 cylinders (charger cylinder unit) located in the charging compartment within the insulated chamber.

Figure 4.18: Insulated chamber; parts assembly and welding line.

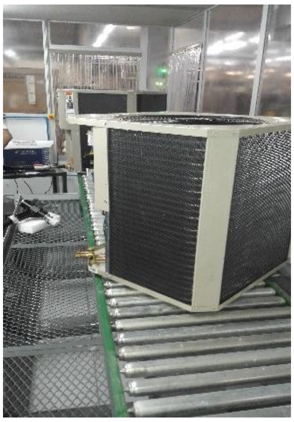


Source: Ozono Technical Unit, Colombia

Figure 4.19: Storage compartment of R290 refrigerant gas (capacity: 4 cylinders, 5.5 kg each); charge and leak test equipment.

Source: Ozono Technical Unit, Colombia

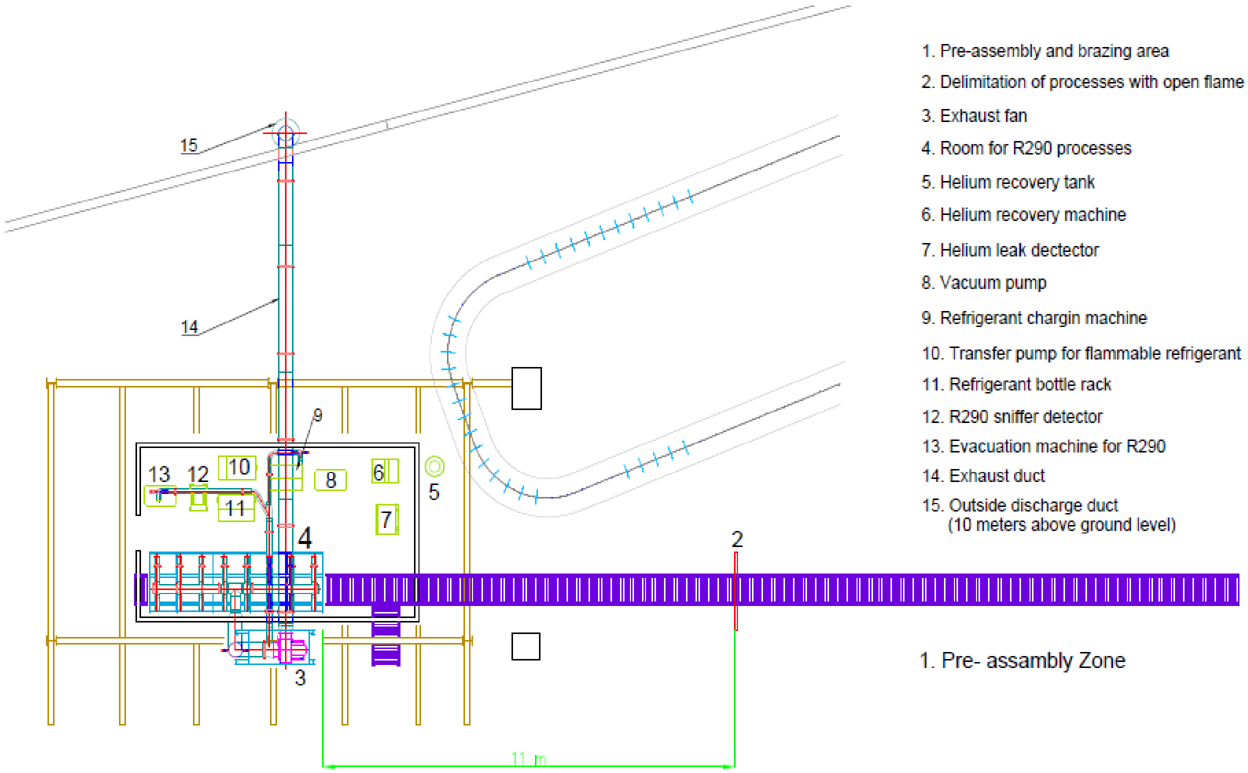
Figure 4.20: Hopper with sensors located inside the isolated chamber and below the HC-290 charging line.



Source: Ozono Technical Unit, Colombia

The several production stages were defined as follows: manufacture of the furniture or metal structure and heat exchangers according to the new designs (processes carried out in the metalwork area), assembly of components and welding (processes carried out in the new line at eleven (11) meters from the hydrocarbon charging area), and the helium-leak test, prevacuum, vacuum, HC-290 charging, and final leak test on the manufactured air-conditioning equipment (procedures performed in the insulated chamber), equipment quality control and packaging (packaging and storage area). It should be noted that any reprocessing due to a non-compliance will be carried out inside the isolated chamber with an independent equipment that performs the hydrocarbon discharge.

Figure 4.21: Drawing of the HC-290 AC manufacturing line



Source: Industrias Thermotar Ltda.

The maximum amount of units produced is twenty (20) units per day, which will depend on the market demand for new equipment.

4.3 Risk assessment of the manufacture line at Industries Thermotar Ltda

The risk assessment of the HC-290 line production process was developed through the provision of information by Industrias Thermotar, a stage carried out through meetings with key staff with extensive knowledge on the HC-290 project, followed by a field inspection to identify the risk conditions this new implementation will entail. This analysis was developed by sectioning the production process, where occurs the HC-290 charging operation, from the receipt of HC-290 cylinders as raw material. Next, we show the partitions of the process for our analysis. Additionally, the study was conducted based on the NFPA 54 National Fuel Gas Code.

- HC-290 receipt and storage operation.
- HC-290 recharge process and transfer systems.
- Risks posed by environmental conditions or neighbouring risks.

The result obtained from the risk assessment study showed that special attention should be paid to the risks surrounding the HC-290 recharging chamber, since the event or risk of fire adjacent to that chamber could have adverse consequences according to the matrices.

Followed by this risk, even though the risks of fire, gas leak and explosion are located in matrix number 2 of the study document or risk assessment (see Annex B), we consider the most critical event for the HC-290 recharge booth would be an explosion event with subsequent fire. It is estimated that the

consequences of this event are not as serious as those of a fire inside the warehouse because it is assumed that the fuel load inside the HC-290 recharging cabin is much lower than the fuel load in the storage warehouse. However, we want to consider that, if the following events are combined, namely, explosion with subsequent fire and damage to the walls of the enclosure, and if the minimum distances of the finished product are not maintained, the fire may spread rapidly to other areas of the plant causing a major scale fire difficult to control with the current resources available for fire control and the current configuration of the plant, which has a single fire area. The technical adjustments made to the manufacture line for the elimination of possible risks identified in the evaluation are presented in section 5.3 (results analysis).

4.4 Training for servicing in installation during guarantee, post-sales services

The training courses included theory and practice and were developed based on the contents proposed by the international expert consultant. The topics of this content are:

– Theoretical module (based on the NTC 6828)
- introduction to refrigerants focused on the handling of hydrocarbon-type refrigerant (HC),
- safety aspects of hydrocarbon refrigerants (HC),
- characteristics of air conditioners, ducted vertical split condensing units with ducts and ducted package-type units that operate with HC-290,
- and safe handling of HC hydrocarbon refrigerants. .

– Practical module
- calculations referring to the verification of the minimum area and maximum charge that should be used for the installation of ducted vertical split condensing units with ducts and ducted package-type units that operate with HC-290,
- performance of leak test or leakage simulation in the equipment through sensors that verified whether the concentration exceeded the lower limit of flammability,
- and an activity on applying good refrigeration practices in the installation, maintenance and removal of these types of equipment devices.

The workshops held during the development of the demonstrative project were:

– Training, education and qualification workshop for technicians or companies of the sector responsible for the installation and maintenance of air-conditioning (AC) equipment with hydrocarbons. (Colombia, October 2017)
– Training and qualification workshop for the instructors or professors of SENA (National Learning Service of Colombia) in charge of the training of the refrigeration and air-conditioning technicians. (Colombia, April 2018)
– Scheduling of training and qualification workshops through the thirty-two (32) SENA centres in the country (Colombia, 2018).

4.5 Workshops for dissemination

The international expert consultant supported the dissemination workshops held during the development of the demonstrative project. The workshops focused mainly on disseminating the results obtained in each phase, which clearly explained issues related to the safe handling and proper management of the risks

associated with the introduction of flammable refrigerants in the commercial air-conditioning sector. The following workshops stand out:

- Presentation on the progress of the demonstrative project in the I International Congress for the Management of Substances that Deplete the Ozone Layer and its Contribution to Climate Stability. (Colombia, Bogotá, September 2017)
- Virtual presentation at Atmosphere Business Case of Natural Shecco – Shecco. (Spain, October 2017)
- Dissemination workshop on the presentation of results from the demonstrative project for the use of HC-290 as an alternative refrigerant in the manufacture of commercial air-conditioning equipment - Industrias Thermotar Ltda. (Colombia, Barranquilla, February 2018)
- Full Paper "SAFE DESIGN OF R290 DUCTED AIR-CONDITIONING EQUIPMENT" submitted for publication at "13th IIR Gustav Lorentzen Conference on Natural Refrigerants"
- Presentation on the results obtained in the 13th IIR-GUSTAV LORENTZEN CONFERENCE ON NATURAL REFRIGERANTS. (Spain, Valencia, June 18, 2018).

5. ANALYSIS OF RESULTS

5.1 Designs and safety assessment of HC-290 based DACS

The analysis of results obtained in the development of the prototypes with designs for explosion protection yielded the following aspects and additional safety measures:

- Both DACS have been designed to minimise the likelihood of a flammable mixture forming around an area beyond the unit housing.
- The evaporator can also be approached, although significant effort is often needed to obtain marginally more than a negligible gain.
- The released masses and mass flow rates have been used within the main study to identify the most appropriate control strategies and estimate leak rates.
- A recommended mitigation measure to reduce the refrigerant charge released was to include a pump-down cycle in the designs, which will reduce the refrigerant charge that can be released into the conditioned enclosure. The above can be seen in the following table:

Table 5.1: Averaged release masses for different leak conditions*

Condition	Released mass (g)	Charge percentage
Shut-down (compr NRV only) → low side leak	420	40%
Shut-down (additional tight NRV)→ low side leak (ducted)	350	35%
Shut-down (additional tight NRV)→ low side leak (rooftop)	300	30%
Low side leak, LP switch → compressor terminates	540	65%
Low side leak, LP switch → shut-down	540	50%
Pump-down → low side leak	90	10%
Compressor off → high side leak	990	90%
Compressor oil de-gassing	20	2%

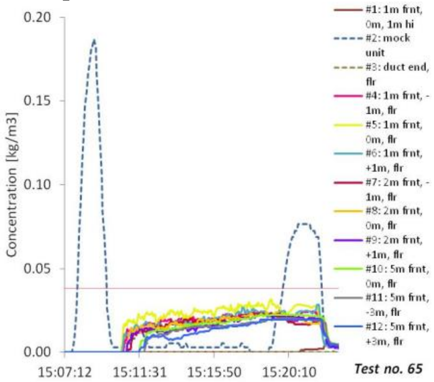
* Differences in the proportion of charge and actual mass are due to variations in charged amounts

Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- The supplementary test with 1,000 g of HC-290 and a high leak rate of 100 g/min was again carried out and results are shown in Figure 5.2. A significant difference is seen here compared to the ducted split AHU case (Figure 5.1), where all sampling positions are well below LFL; still supporting the assumption that increased falling velocity from the higher level ultimately helps to disperse the release before falling to the room floor.

Figure 5.1: Mock elevated AHU and associated single ducting

Figure 5.2: 1000 g release at 100 g/min from ceiling level mock rooftop with plenum at 1.5 m elevation

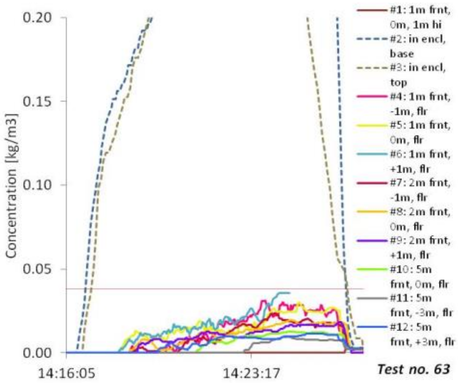


Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- Recommended mitigation measures for the AHU enclosure (low side): To this end, a plenum chamber was constructed around the outlet of the AHU so that any released refrigerant must flow over the upper lip before it flows across the room floor; this additional height is intended to help accentuate the dispersion of refrigerant as it enters the room. Four elevations of plenum chamber – 0.25 m, 0.50 m, 1.0 m and 1.5 m – were tested, as indicated in Figure 27.

Figure 5.3: Elevations of outlet plenum; 1.5 m

Figure 5.4: 350 g release at 50 g/min from ducted split AHU with plenum at 1.5 m elevation



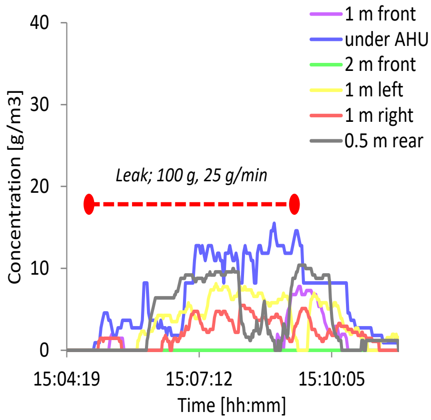
Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne

- As a result of the above, the company designed a new AHU, on which the previous tests were carried out in the same way. The results obtained were positive.

Figure 5.5: Typical contents of electrical panel

Figure 5.6: Example of evaporator fan motor

Figure 5.7: Example of fan blades



Source: Designs and safety assessment of Thermotar AC units for application of HC-290 – Interim Report. Daniel Colbourne.

– The modifications defined for the removal of the SOI, namely, separating the electrical panel, will ensure that if a technician inadvertently fits an unsuitable component after the units has been installed, there remains no residual risk that it could act as a SOI to a refrigerant leak.

  The leak simulation test performed (pursuant to NTC 6228-2), showed that the revised construction prevents contact with a concentration exceeding 50% LFL.

Figure 5.8: Insulated electrical box

Source: Industrias Thermotar Ltda.

– Performance tests on a ducted split condenser unit prototype: Industrias Thermotar performed these tests pursuant to the ISO 5151: 2017 standard, which specifies the standard conditions and the test methods for determining the capacity and efficiency of air-cooled air conditioners and air-to-air heat pumps. Additionally, these tests are being corroborated by a certified laboratory in Colombia.

Table 5.2: Results of comparative testing of HCFC-22, R-410A and HC-290 5-TR AC equipment.

Parametros	Split central HCFC-22	Split central R-410A	Split central HC-290
Rated capacity (BTU / h)	60000	60000	60000

Supply (V)	440	440	440
Phases	3	3	3
Frequency (Hz)	60	60	60
Operating time (Hr)	4	3,5	3,5
Refrigerant charge (g)	2265	2404	1000
Temp. Dry Bulb Supply (ºF)	54,2	54,0	53,9
Relative Humidity (%)	78,7	79,2	80,1
Temp. Dry Bulb Return (ºF)	72,8	73,5	74,0
Relative Humidity Return (%)	51,8	51,9	50,1
Low pressure (PSIG)	65,0	135,0	65,0
Ambient Temp. (ºF)	94,0	95,0	96,0
High pressure (PSIG)	245,0	370,0	215,0
The input electrical power of compressor (W)	4475,0	4350,0	3780,0
Difference in the electrical power consumption between an conventional equipment HCFC-22 to a conventional equipment R-410A and a new equipment HC-290 (%)	0,0	-3,0	-15,6
Difference in the eletrical power consumption between an conventional equipment R-410A to conventional equipment HCFC-22 and a new equipment HC-290 (%)	2,9	0,0	-13,1

Source: Industrias Thermotar Ltda.

Lessons learned: Human Intervention in DACS is the most likely cause of accidents. Therefore, it was essential to ensure that the DACS design was such that technicians and other staff were given limited scope to interfere with the safety features associated with the HC-290 DACS. For this reason, designs have three identification measures and leak Reponses: Cabin or metal structure to isolate the electrical box and increase ventilation around the unit, pumping cycle (Pump Down) and ultrasound sensor. Moreover, it is critical for the national infrastructure to be prepared to minimise the possibility of untrained or non-competent technicians involved in the installation, servicing and decommissioning of HC-290 DACS.

5.2 Manufacture line for production of air-conditioning (AC) equipment with HC-290

The new installed production line has the safety measures required for the safe handling of the hydrocarbon refrigerant. These measures were supported by both the company in charge of supplying the equipment for the manufacture of the ACs and the risk assessment carried out on the new line. Moreover, the training provided to the operators in charge of the equipment is an important step to apply good manufacturing practices in the company Industrias Thermotar Ltda.

Learned lessons: There are already suppliers of equipment to manufacture refrigerators and air conditioners with flammable refrigerants in the international market. But the most important feature that should be considered for the assembly of this line are the space and civil works required within the facilities; therefore, using an insulated chamber contributes to the safe handling of this flammable refrigerant gas within the company.

Once the suggested recommendations have been presented through the risk assessment study, Industrias Thermotar Ltda. made the necessary technical modifications to correct the deficiencies identified. Consequently, a follow-up exercise of recommendations is carried out once more to check compliance

with the standards; this activity is a duty of the specialist firm dedicated to implement these types of projects.

The most important corrections are, among others:

Figure 5.9: Civil and technical adaptations to the exterior and interior of the storage room (ventilation system)

Source: Engrin de Colombia SAS (SURA)

Source: Engrin de Colombia SAS (SURA)

Figure 5.10: Introduction of restrictions to the storage of finished product inside the plant in general

Source: Engrin de Colombia SAS (SURA)

Figure 5.11: Installation of a pedestal with a safety chain to prevent the fall of the Helium cylinder.

Source: Engrin de Colombia SAS (SURA)

Figure 5.12: Additional sensor installations in the HC-290 recharging chamber.

Source: Engrin de Colombia SAS (SURA)

Source: Engrin de Colombia SAS (SURA)

Learned lessons: The risk assessment study must consider other stages not in the manufacturing line such as: storage of non-returnable cylinders with hydrocarbon as raw material, and storage of the final product. On the other hand, to increase the safety level of the manufacturing line, it is feasible to consider installing other sensors in addition to the current equipment sensors of the manufacturing line, as well as, consider the explosion-proof lamps within.

5.4 Training for servicing in installation during guarantee, post-sales services

This phase is the most important challenge posed by the demonstrative project, and should be considered as a permanent phase in the country; to this end, it must be included in the different programs related to the training and qualification of the refrigeration and air-conditioning service sector.

The follow-up plan prepared by Industrias Thermotar Ltda. partially supports the challenge faced by the country in relation to the training and education of technicians in the service sector. This plan is part of the post-sales strategy that should be implemented by the technical services of HC-290 AC systems installation, maintenance and repair.

Having a public learning system in the country, such as the SENA centres, makes it possible to train the sector not only in the management of hydrocarbon refrigerant gases, but also in the handling of HFOs or other refrigerant with some hazardous attributes.

Learned lessons: To face the training and education of the service sector in the best way possible, it is necessary to have a network of training or education centres that can certify the sector's technicians in the safe handling of hydrocarbons and other refrigerant gases with medium flammability. Additionally, it is necessary to update or adopt international standards regarding the safety and environmental requirements necessary in refrigeration systems and heat pumps.
The follow-up plan is binding not only on Industrias Thermotar Ltda., but also on the users or customers who acquire this equipment as they must guarantee the safe handling and proper management of risks associated with the introduction of these flammable refrigerants in the commercial air-conditioning sector. The strategy or plan includes the monitoring and follow-up of the first units installed in the commercial sector.

5.5 Workshops for dissemination of results

The dissemination workshops communicated and fully presented the main results obtained through the demonstrative project. Likewise, the paper or study prepared in conjunction with the international expert consultant represents the positive and significant results that influence technical aspects in the technological development related to the use of refrigerant gases with insignificant GWP and zero ODP.

6. INDUSTRIAL HYGIENE & SAFETY

The risk assessment study carried out on the manufacture line of HC-290 AC, not only included the manufacture line but also the plant in general, which is why the emergency plan of the security management system of Industrias Thermotar Ltda. was complemented by including the control measures for responding to emergencies caused by the handling of HC-290, as well as the safety measures for prevention of combustion and explosions.

7. INCREMENTAL COSTS

The incremental costs of the demonstrative project are divided into incremental capital costs and incremental operating costs. Within the incremental capital costs, the costs associated with the activities carried out were discriminated taking into account the economic contributions made by Industrias Thermotar Ltda, as well as those defined in the UNDP Project COL101294.

For the incremental operating costs, the 5 TR DACS models that work with HCFC-22 and R-410A were compared to the new HC-290 designs.

7.1 Incremental capital cost

Table 7.1 Incremental capital cost.

ITEM	DESCRIPTION	FINANCED BY	UNIT	QUANTITY	UNIT VALUE (USD$)[13]	SUB - TOTAL (USD$)
1.0	**PRELIMINARY**					
1.01	Preliminary documentation - presentation of the demonstrative project, analysis of risk vulnerability in the production plant, description and assessment of the project impacts.	THERMOTAR	-	1	$1,620.59	$1,620.59
1.02	Project Engineer - 30 months (7200 Hr)	THERMOTAR	HOUR	7200	$12.73	$91,669.70
					SUBTOTAL	**$93,290.29**
2.0	**INTERNATIONAL CONSULTANT**					
2.01	Hiring of international expert (Travel and commissions)	PROJECT[14]	DAYS	83	$870.00	$73,080.00
					SUBTOTAL	**$73,080.00**
3.0	**DESIGN, CONSTRUCTION AND PROTOTYPE TESTING**					
3.01	Advisory by the design department, intervention by the production and quality department / SST	PROJECT	HOUR	3500	$10.91	$38,192.07
3.02	Constructions or manufacture of prototypes and final designs of DACS for HC-290	PROJECT	UNIT	18	$1,849.16	$33,284.83
3.03	HC-290 Refrigerant Cylinder X 5.5 KG / 12.1 LB	THERMOTAR	UNIT	42	$67.53	$2,836.26
3.04	Instrumentation equipment for prototype testing, supplies for conducting safety tests, drills and performance testing in prototypes	THERMOTAR	-	1	$18,486.49	$18,486.49
3.05	New line of compressors for tests with HC-290 Models ZH13KCU imported by air	THERMOTAR	UNIT	10	$891.23	$8,912.33
3.06	Testing of prototypes in a national certified laboratory (transport, accessories and test costs)	THERMOTAR	UNIT	2	$2,309.93	$4,619.86
3.07	Testing of electric motors in laboratories (Shipping costs, nationalization, test)	THERMOTAR	UNIT	2	$2,673.70	$5,347.40
					SUBTOTAL	**$111,679.24**
4.0	**PRODUCTION PLANT ADAPTATIONS**					
4.01	Adaptations to conveyor rack with rollers	PROJECT	MTS	30	$127.32	$3,819.57

[13] Exchange rate used for calculations: 2,749 $US / $COP

[14] PNUD Colombia. 2016. PRODOC, Output ID 000101294 Project ID 000101294. Demonstration project for the use of HC-290 (propane), as an alternative refrigerant in the manufacture of commercial air conditioning equipment at Industrias Thermotar Ltda.

4.02	Electrical restructuring of the transport rail, grounding, connection accessories and labour, paint work of production plant, redistribution of oxyacetylene, nitrogen and compressed air sources, and additional adjustments recommended in the risk assessment	PROJECT	-	4	$2,273.55	$6,857.04
4.03	87 m^2 cabin construction for the HC-290 charging area	PROJECT	-	1	$6,129.50	$6,129.50
4.04	Ductwork and exhaust channels for flammable gases. Exhaust pipe for flammable gases that go from the extraction channel to the Explosion Proof extractor motor.	PROJECT	-	1	$8,695.16	$8,695.16
4.05	HC-290 cylinder storehouse adaptations: Extraction system (fan, ducts and support), propane gas sensors, and integrated security alarm system	PROJECT	-	1	$5,951.26	$5,951.26
					SUBTOTAL	**$31,452.53**
5.0	**ACQUISITION OF MACHINERY AND EQUIPMENT FOR THE HC-290 PRODUCTION LINE, INSTALLATION AND MAINTENANCE**					
5.01	Helium leak test system with Sniffer detector and Helium recuperator	PROJECT	-	1	$63,320.93	$63,320.93
5.02	Vacuum pump with process controller	PROJECT	-	1	$6,085.39	$6,085.39
5.03	Evacuation and charging equipment for flammable refrigerant (HC-290)	PROJECT	-	1	$40,614.60	$40,614.60
5.04	Equipment for safe discharge and disposal of flammable refrigerant (HC-290)	PROJECT	-	1	$11,218.88	$11,218.88
5.05	HC-290 detector equipment for leakage test in repair and rework area	PROJECT	-	1	$18,188.18	$18,188.18
5.06	Integrated safety monitoring and control system for flammable gases	PROJECT	-	1	$6,980.64	$6,980.64
5.07	Ventilation system for flammable gases (Without ductwork)	PROJECT	-	1	$10,000.00	$10,000.00
5.08	Supplies for spares, assembly and equipment operation	PROJECT	-	1	$4,284.70	$4,284.70
5.09	Pre-engineering design for civil works in plant	PROJECT	-	1	$5,610.00	$5,610.00
5.10	Installation, start-up and training in handling of equipment.	PROJECT	-	1	$4,950.00	$4,950.00
5.11	Flammable refrigerant pneumatic transfer pump	PROJECT	-	1	$10,565.00	$10,565.00
5.12	Accessories for equipment handling in production process	PROJECT	-	1	$2,132.85	$2,132.85
5.13	Tools and accessories for copper tubing coupling by pressure	PROJECT	-	1	$8,065.67	$8,065.67
5.14	Other expenses (taxes, expenses at destination, freight certificate, customs agent fees)	PROJECT	-	1	$31,807.16	$33,869.71
					SUBTOTAL	**$225,886.55**
6.0	**TRAINING AND QUALIFICATION OF ENGINEERS, TECHNICIANS AND OPERATORS**					
6.01	Training materials for training courses and prototype equipment for manipulation during training, training material	PROJECT	-	1	$1,911.60	$1,911.60
6.02	Transport and missions of participants	PROJECT	-	6	$974.33	$5,846.00
6.03	International Consultant (Training)	PROJECT	DAYS	6	$330.00	$1,980.00
6.04	National consultant monitoring and development of BPR workshops	PROJECT	YEAR	1	$16,342.86	$16,342.86
6.05	National training strategy for technical training	PROJECT	WORKSHOP	7	$2,000.00	$14,000.00
6.06	Preparation of the follow-up plan	PROJECT	STUDY	1	$4,300.00	$4,300.00
6.07	Follow-up plan implementation. 6 months, first 30 units manufactured.	THERMOTAR / PROJECT	UNIT	30	$187.00	$33,660.00
					SUBTOTAL	**$78,040.46**
7.0	**RISK ASSESSMENT OF HC-290 AC MANUFACTURE LINE**					

7.01	Document containing the safety procedures related to the handling of the R290	PROJECT	STUDY	1	$1,820.00	$1,820.00
7.02	Certificate or document evidencing the risk assessment study carried out on the manufacture line	PROJECT	STUDY	1	$2,450.00	$2,450.00
					SUBTOTAL	**$4,270.00**
8.0	**DISSEMINATION WORKSHOPS**					
8.01	Dissemination workshops (International tickets, travel expenses, related documentation)	PROJECT	-	3	$32,568.00	$32,568.00
					SUBTOTAL	**$32,568.00**
9.0	**ADDITIONAL GENERAL COSTS**					
9.01	Other expenses, general documentation (Stationery)	THERMOTAR	-	2	$591.12	$591.12
9.02	Transport and travel expenses of project engineer (Training and project presentations)	THERMOTAR	-	1	$1,218.62	$1,218.62
9.03	Signs, warnings and banners for presentations and training	THERMOTAR	-	1	$1,136.78	$1,136.78
					SUBTOTAL	**$2,946.52**
					TOTAL (USD)	**$653,213.60**

Source: Industrias Thermotar Ltda. and Ozono Technical Unit, Colombia

7.2 Incremental operating cost

- Ducted split condensing units:

Table 7.2 Incremental operating cost. Split unit 5 TR

Incremental Operating Cost DACS: Split unit 5 TR (8 mm-diameter copper exchanger within the condenser)						
Incremental cost[15] by platform (USD $ per unit)		Cost with R-410A	Cost with HCFC-22	Cost with HC-290	Difference	
					R-410A vs R290	HCFC-22 vs HC-290
Air-Handler unit	Cabinet (Structure)	$165.51	$165.51	$190.98	**$25.46**	**$25.46**
	Refrigerant charge	$0.00	$0.00	$0.00	**$0.00**	**$0.00**
	Main operation components (Compressor, condenser motor, blower motor, blower, blade, copper pipe, filter drier, pressure switches, solenoid valves)	$412.15	$412.15	$424.15	**$12.00**	**$12.00**
	Electric components and accessories for safety, control and power	$15.46	$15.46	$27.28	**$11.82**	**$11.82**
	Refrigerant cost (Cost per Pound)	$0.00	$0.00	$0.00	**$0.00**	**$0.00**
Condenser unit	Cabinet (Structure)	$110.95	$110.95	$110.95	**$0.00**	**$0.00**
	Refrigerant charge	$38.20	$20.01	$11.46	**- $26.74**	**- $8.55**
	Main operating components (Compressor, condenser motor, blower motor, blower, blade, copper tubing, filter drier, pressure switches, solenoid valves)	$771.19	$740.27	$879.23	**$108.04**	**$138.96**
	Electrical components and accessories for safety, control and power	$15.30	$15.30	$42.13	**$26.83**	**$26.83**
	Refrigerant cost (Cost per Pound)	$2.91	$1.15	$1.89	**-$1.02**	**$0.75**
TOTAL		**$1,531.67**	**$1,480.80**	**$1,688.07**	**$156.40**	**$207.28**

Source: Industrias Thermotar Ltda.

Manufacturing a 5-TR split unit equipment with HC-290 costs 10% more than manufacturing a 5-TR split unit with R-410A. This increase is mainly due to the cost associated with the compressor, and other such as the electric components and accessories for safety, pressure switches and solenoid valves.

[15] Exchange rate used for calculations: 2,749 $ US/$ COP

– Rooftop unit with duct:

Table 7.3 Incremental operating cost. Rooftop unit 5 TR

Incremental Operating cost DACS: 5 TR Rooftop unit (8 mm-diameter copper exchanger within the condenser)					
Incremental cost by platform (US $ per unit)[16]	**Cost with R-410A**	**Cost with HCFC-22**	**Cost with HC-290**	**Difference**	
				R-410A vs R290	**HCFC-22 vs HC-290**
Cabinet (Structure)	$245.54	$245.54	$265.55	**$20.01**	**$20.01**
Refrigerant charge	$38.20	$20.01	$11.46	**- $26.74**	**- $8.55**
Main operation components (Compressor, condenser motor, blower motor, blower, blade, copper pipe, filter drier, pressure switches, solenoid valves)	$1,089.49	$1,094.94	$1,218.62	**$129.14**	**$123.68**
Electric components and accessories for safety, control and power	$63.66	$63.66	$116.41	**$52.75**	**$52.75**
Refrigerant cost (Cost per Pound)	$2.91	$1.15	$1.89	**-$1.02**	**$0.75**
TOTAL	**$1,436.89**	**$1,424.15**	**$1,612.04**	**$175.15**	**$187.89**

Source: Industrias Thermotar Ltda.

Manufacturing a 5-TR split unit equipment with HC-290 costs 12% more than manufacturing a 5 TR split unit with R-410A. This increase is mainly due to the cost associated with the compressor, and other such as: The electric components and accessories for safety, pressure switches and solenoid valves.

8. CONCLUSIONS

[16] Exchange rate used for calculations: 2,749 $ US/$ COP

The demonstrative project complied with the objectives that were proposed by its execution. The following conclusions no only show the general inferences but also include specific conclusions

General conclusions:

- HC-290 based DACS have been developed within the project to demonstrate the safe use of HC-290 (propane) as a low GWP refrigerant in the commercial production of air-conditioning. Commercial production has not yet begun, however, there are a few prototype DACS already installed and are being monitored. Through QRA and using – typically pessimistic – assumptions about the installation and operational conditions, the developed products can be considered as **"safe".**
- The only DACS developed on HC-290 are the 17.5 kW ducted split and rooftop models, with the QRA carried out on both of these. The same concepts and technical feature will be applied equally to these smaller units as for the 17.5 kW unit, thus all designs are feasibility.
- Throughout the development process prototypes were regularly checked for performance. The most recent findings indicated the same cooling capacity as the baseline DACS and a lower electrical power consumption, thus giving a higher COP[17].
- Selections of specific design features have been developed to help mitigate flammability risk. Several of these incur incremental operating costs. This increase is low (10% more than R-410A based DACS) and by the future its reduction depends on the supply in the market of the differents parts, mainly the compressor (HC-290).
- Necessary security features and conditions have been integrated into the new DACS designs. However, addressing safe handling and good flammability risk management is predominantly achieved through company-wide and national technician training, assessment, certification and registration schemes and associated changes to company conditions of sale and warrantee agreements; this is beyond the remit of product design and development.
- According to current design, each kg of HCFC-22 can be replaced with approximately 0.4 kg of HC-290 in any DACS of broadly the same design and construction. For this reason, Industrias Thermotar Ltda. with the closure of its production line of AC equipment with HCFC-22 is removing 13.75 metric tons of HCFC-22 from national consumption rates.

Specific conclusions:

- The HC-290 AC models (DACS) developed meet the technical requirements related to the tightness of the system and the removal of ignition sources. This is based on the testing carried out on mass of refrigerant released, leakage rates and concentrations of HC-290 inside and around the units, and along the pipelines.
- The technical modifications implemented in the HC-290 AC models are based on the integration of a leak-identification and response system, which consisted of: redesign of the furniture or metal structure to insulate the electrical box, increase of the ventilation around the unit, and installation of a pump cycle (Pump Down) and an ultrasonic sensor in the condenser unit and evaporator respectively.
- The most representative change in relation to the design, in the HC based model, was in the handling unit (AHU). The air intake opening was located laterally, one meter (1 m) above the floor level.
- The reduction of the refrigerant charge in the HC-290 AC model was significant. The charge of HC-290 for the largest unit (5 TR split condensing unit, with 8 mm tube diamenter for the condenser and 3 meters of pipe) was 1000 grams.

[17] COP: Coefficient of performance

- When leaks occur in the AC designs, the pump down cycle reduces the load within the handling unit (within the conditioned enclosure) to approximately 10% (100 grams) of the total equipment load.
- In relation to energy consumption, an HC-290 5TR split unit equipment (HC-290 scroll compressor) consumes 13.1% less energy (kWh) than a similar R-410A unit.
- Manufacturing a split 5-TR unit with HC-290 costs 10% more than manufacturing a split 5-TR unit with R-410A; likewise, manufacturing a 5-TR rooftop unit HC-290 costs 12% more than manufacturing a 5-TR rooftop unit with R-410A. This increase is mainly due to the cost associated with the compressor and other such as the electric components and accessories for safety, pressure switches and solenoid valves.
- The AC equipment manufacture line with HC-290 has a production capacity equivalent to twenty (20) units per day.
- The helium tightness test that is performed inside the production chamber will largely reduce the non-conformities of the finished product.
- The risk assessment carried out on the HC-290 equipment manufacture line considered the analysis of the most representative impacts including storage, internal transport and HC handling in the refrigerant charging or precharging area. In essence, the new line has the protection measures that the foresaid line must have in order to guarantee its correct operation before, during and after each activity to recharge DACS with HC-290.
- The HC-290 storage area and insulated chamber have the necessary safety measures to identify and eliminate any leaks arising within these spaces. These measures are linked to the electrical lines of the manufacturing plant, so that the manufacturing plant is de-energized once the explosion-proof extractors are activated.
- The demonstrative project had a training and education strategy focused on the service sector. Initially it was intended for the companies and technicians that are part of Industrias Thermotar Ltda. staff, responsible for the installation and maintenance of company equipment, but the strategy is now permanent with a national scope.
- NTC 6828 defines the steps that must be considered for the installation and maintenance of RAC equipment with refrigerants that have some hazardous attributes, such as A3 (HC-290). The service sector must calculate a minimum area or maximum charge required before installing these new designs or equipment with flammable or toxic refrigerants.
- The follow-up plan developed by Industrias Thermotar Ltda. will support the monitoring and control strategy for the first units manufactured and reduce the risks associated with the use of hydrocarbon refrigerant.

9. RECOMMENDATIONS

9.1 Execution recommendations

It is necessary to consider a longer time for the development of this kind of demostrative project that include the re-design of equipment for the use of flammable refrigerants in the RAC sector. Design of protypes requires an iterative risk assessment and risk analysis, for this reason it is suggested to take in account at least two years for this activity.

9.2 Technicals recommendations

According to the report that was developed by International Expert it is necessary to carry out the following technical aspects:

- Re-calculation of electric equipment fault probability based on service database (DC).
- Estimate the probability that technicians may not replace one or more base panels on the new. AHU following a service or would not follow instructions that air return ducts should be installed at least 1 m above the floor.
- Explore redesign alternatives for finned-tube evaporator for further charge reduction (DC).
- Perform additional measurements to demonstrate effectiveness of ultrasonic leak detection.
- Confirmation on the type of internal overload protectors used on the blower fan motors, and compliance certificate for fan motors to IEC 60079.
- Compliance certificate for low and high pressure switches to IEC 60079.
- More comprehensive assessment of the latest factory performance testing.

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ANNEX A. Designs and safety assessment of Thermotar AC units for HC-290 application – Interim Report.

ANNEX B. Risk assessment studies